USE OF ATMOSPHERIC REFRACTION TO DETERMINE AIR MASS AND EXTINCTION COEFFICIENTS AS WELL AS TEMPERATURE AND HUMIDITY PROFILES IN THE MARINE BOUNDARY LAYER

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LONG-TERM GOALS

Our long term goals are to develop algorithms and techniques to extract as many atmospheric parameters as possible, such as air mass and extinction coefficients as well as temperature and humidity profiles, in the marine boundary layer by comparing both actual and apparent heights shapes and brightness of objects lying close to the horizon. This methodology is presently being tested by using the rising or setting sun/moon as the source, and will later be extended to include artificial sources.

OBJECTIVES

The objective of this proposal is to use the phenomenon of atmospheric refraction to determine not only air mass and extinction coefficients but also the temperature and humidity profiles over the marine boundary layer. Theoretical analysis is coupled to measurements off the San Diego coast to determine the efficacy of the technique.

APPROACH

 We are comparing observations of boundary-layer phenomena with numerical simulations, using appropriate models. The observations are made photographically, using a telephoto lens combination with an effective focal length of 1 meter. The numerical simulations are done on UNIX workstations using programs specially developed for accurate ray-tracing.
One of the key individuals in our program is Dr. Andrew T. Young (San Diego State University) who is responsible for sunset photography, and for drafting papers on refraction and extinction in the marine boundary layer.

We have also been able to develop a computer program, based on the Abel integral transform, which allows us to obtain a unique temperature profile from a sequence of images of the setting sun. The way this is done is to scan the images into our computer and then use edge finding software to determine the shape of the solar disk. The inversion algorithm is then used on these shapes to determine the unique temperature profile of the region of atmosphere below the observer.

WORK COMPLETED

We have photographed a large number of sunsets, and are continuing this work to get good sampling of the range of phenomena that occur. We now have about two dozen sunsets photographed simultaneously

1

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from two (and in several cases, three) different heights above sea level. We have done exploratory modeling of boundary layers containing both ducting and non-ducting thermal inversions at low levels, as well as boundary layers with super-adiabatic gradients, which produce the inferior mirage. The continuing literature search is still turning up useful references, such as the paper on ducting and superior mirages by Haug[1] , and we will continue to explore the literature's of astronomy, meteorology, geophysics and hydrography to locate useful material.

We have completed one phase of our studies of the mock mirage which has resulted in two publications[2,3].

We have also completed one phase of our studies on the inversion of solar image profiles to obtain unique temperature profiles which has resulted in a publication[4].

RESULTS

 What we have learned from our work on the mock mirage[2,3] is not only that thermal inversions can produce more complex phenomena than has been previously suspected, but also that not all the "textbook" explanations of mirage phenomena are correct; we must be careful to re-examine supposedly well-established ideas, particularly those not supported by detailed modeling. Through use of a dip diagram, which makes visible the information contained in the refractive invariant, we have learned that, even in conditions that produce mirages or pseudo-mirages (i.e., conditions that invert a zone of sky near the apparent horizon), the "vertex" or tangent height of each line of sight is a monotonic function of apparent altitude. This explains the relatively undistorted appearance of ships on the horizon even when the Sun is heavily distorted behind them.

 What we have also learned from our work on solar disk inversion, is that the unique profiles we obtain using our algorithm are extremely accurate[4]. We illustrate this in Fig. 1. The upper image is a simulated omega sunset which we generated using the input temperature profile shown in the lower graph and where the observer is 50 m above the ocean surface. The lower graph shows the true profile used to generate the omega sunset above and the temperature profile obtained from the inversion algorithm using the Abel integral transform. The agreement between the true profile and that from our inversion algorithm is almost perfect. To our knowledge this is the first time a detailed profile of the temperature in the marine boundary layer has been obtained using only the shape of the solar disk as the source.

IMPACT/APPLICATION

The discovery (last year) of the mock mirage suggests that not only astronomical but also terrestrial pseudo-mirages can occur. We already have a photograph of a triple horizon that may require such a mechanism for its explanation. Young has also found that a pseudo-mirage associated with ducting, and related to Wegener's "Nachspiegelung", can produce huge green flashes. It seems that the study of both ducts and pseudo-mirages in general will open up an area in atmospheric optics that has not previously been recognized. Just as mock mirages have been photographed for years but not correctly interpreted, it may well turn out that other relatively common phenomena have been incorrectly interpreted. These examples point out the importance of detailed, quantitative modeling in place of arm-waving, qualitative explanations.

Our inversion scheme should be very useful to the operational Navy since once the temperature profile is obtained, it can then be used to deconvolute distorted images of ships and missiles.
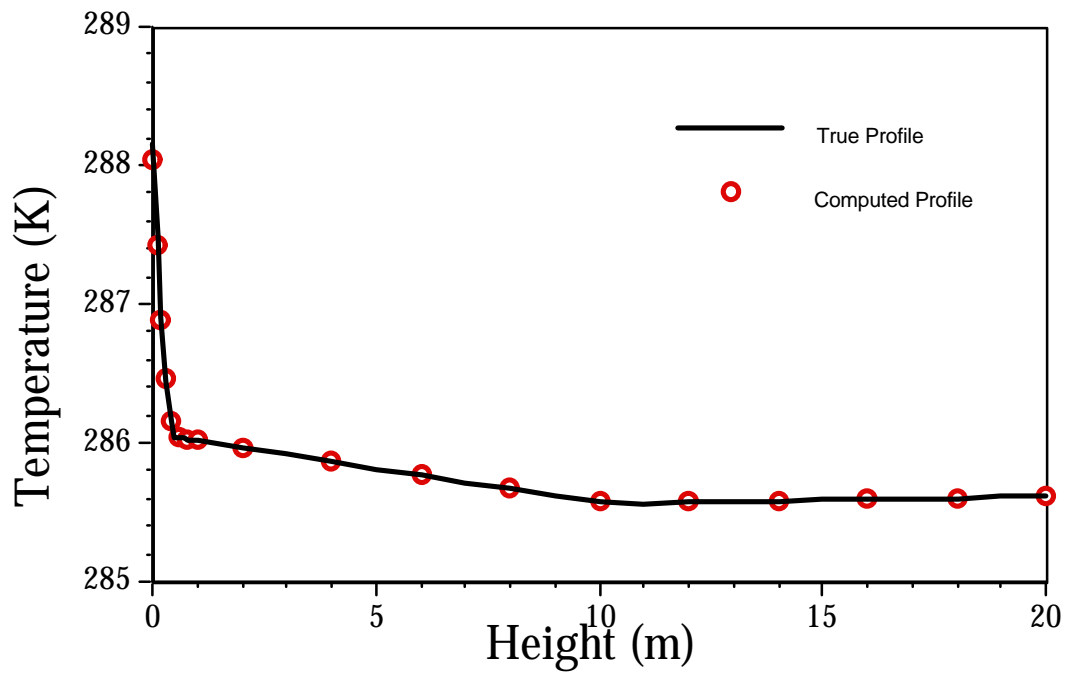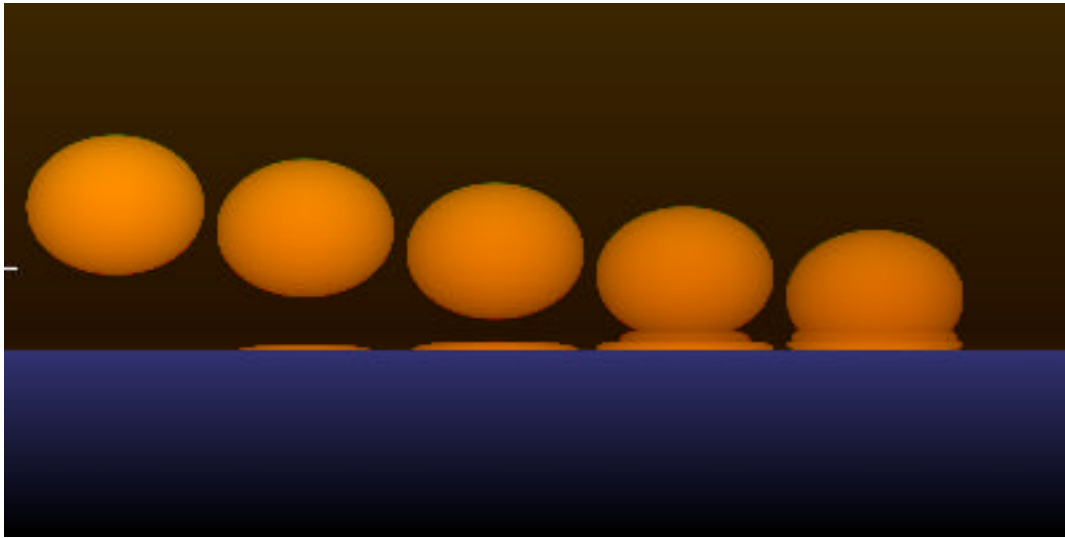
Fig.1 The upper image is a simulated omega sunset where the observer is 50 m above the ocean surface. The lower graph shows the true profile used to generate the omega sunset above and the temperature profile obtained from the inversion algorithm using the Abel integral transform. The agreement between the true profile and that from our inversion algorithm is almost perfect.

TRANSITIONS

We have had occasional correspondence with Dr. Lutz Hasse of the Institut fuer Meereskunde in Kiel, Germany, concerning dip and related issues. He has expressed an interest in our work, and provided several useful references, such as Rudolf Meyer's[5] review in "Handbuch der Geophysik".

We continue to exchange information with Lu Rarogiewicz at Mt. Wilson, who is working with George Kaplan at USNO on refraction problems.

George Coyne of the Vatican Observatory has made slides of the distorted sunset sequences shown in O'Connell's book on the Green Flash available to us for measurement. Our recent work with the dip diagram shows, in principle, how ships silhouetted against the distorted Sun in these pictures can be relatively undistorted; however, we still need to work out detailed models for these images.

RELATED PROJECTS

ATY has submitted a proposal to NSF to investigate the details of the green flash phenomena, which are observed in several of our photographs. No funding decision has yet been made by NSF on this related project.

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